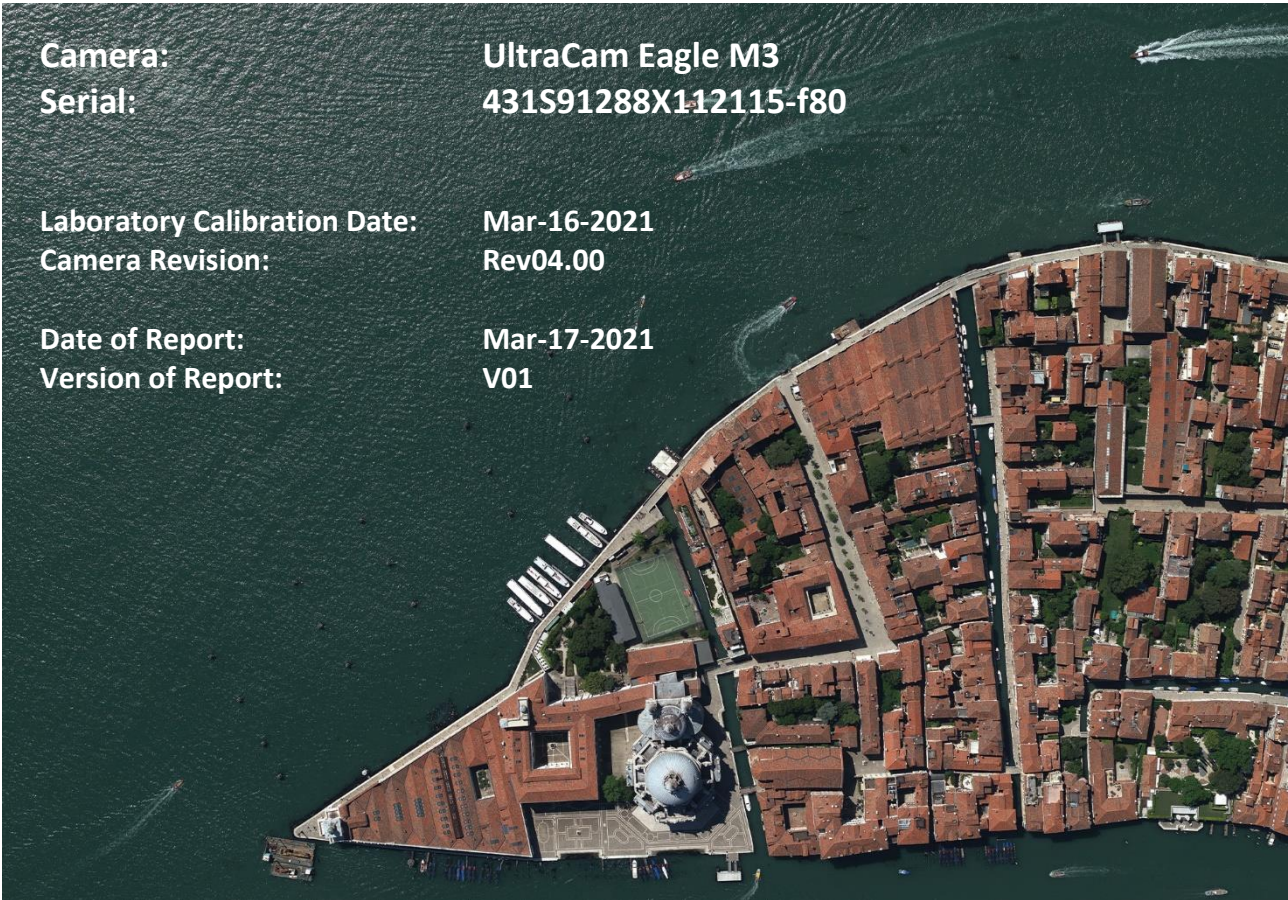




ULTRACAM

Calibration Report



Camera: UltraCam Eagle M3
Serial: 431S91288X112115-f80

Laboratory Calibration Date: Mar-16-2021
Camera Revision: Rev04.00

Date of Report: Mar-17-2021
Version of Report: V01

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Venice, Italy

Photo on page 1 courtesy of Vexcel Imaging GmbH



ULTRACAM

Geometric Calibration

Camera: UltraCam Eagle M3
Serial: 431S91288X112115-f80

Panchromatic Camera: ck = 79.800 mm
Multispectral Camera: ck = 79.800 mm

PPA Information: X: 0.000 mm
Y: 0.000 mm



Panchromatic Camera

Large Format Panchromatic Output Image

Image Format	long track cross track	68.016mm 105.840mm	17004pixel 26460pixel
Image Extent		(-34.008, -52.920)mm	(34.008, 52.920)mm
Pixel Size		4.000µm*4.000µm	
Focal Length	ck	79.800mm	± 0.002mm
Principal Point (Level 2)	X_ppa	0.000mm	± 0.002mm
	Y_ppa	0.000mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		

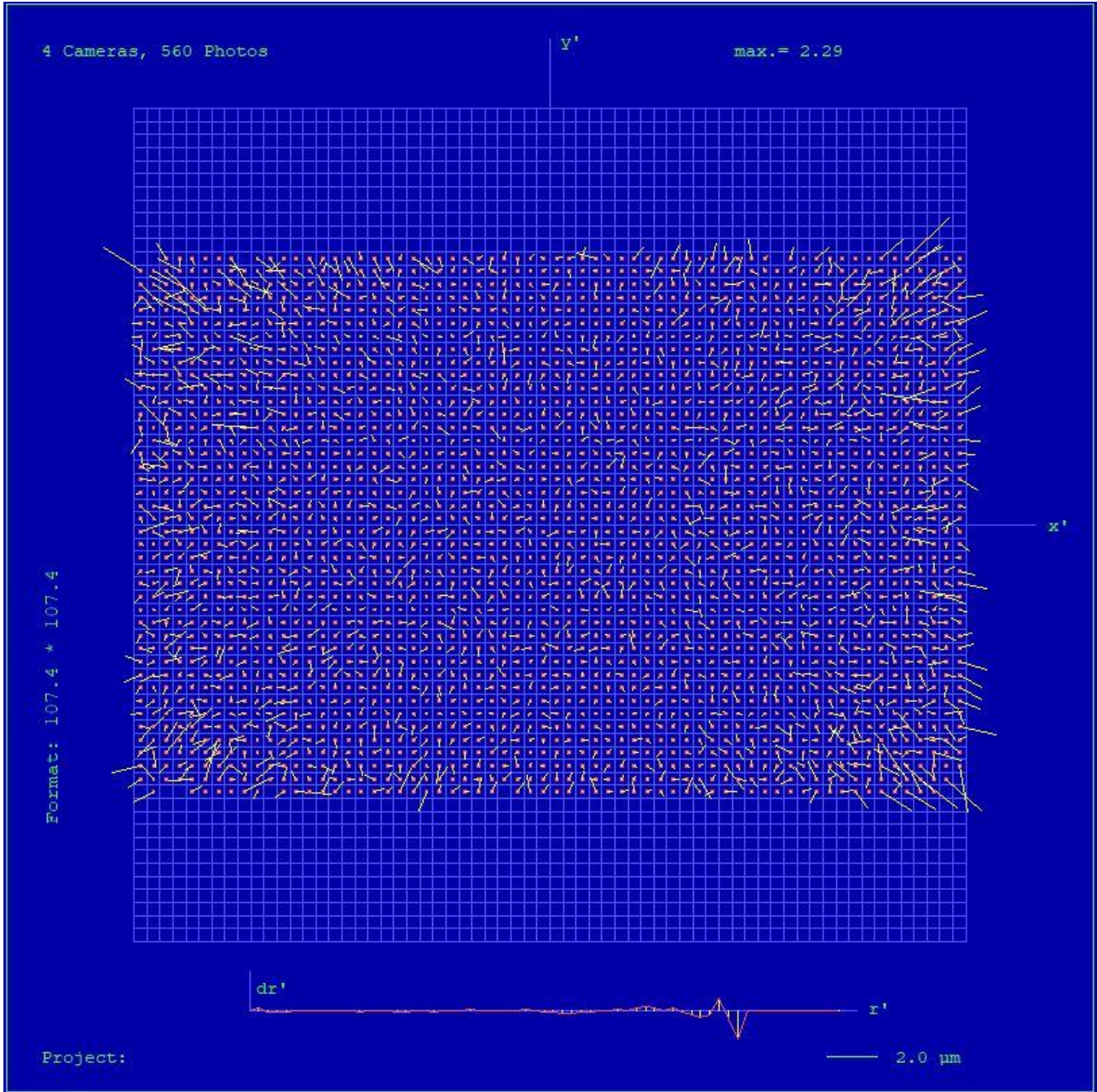
Multispectral Camera

Medium Format Multispectral Output Image (Upscaled to panchromatic image format)

Image Format	long track cross track	68.016mm 105.840mm	5668pixel 8820pixel
Image Extent		(-34.008, -52.920)mm	(34.008, 52.920)mm
Pixel Size		12.000µm*12.000µm	
Focal Length	ck	79.800mm	± 0.002mm
Principal Point (Level 2)	X_ppa	0.000mm	± 0.002mm
	Y_ppa	0.000mm	± 0.002mm
Lens Distortion	Remaining Distortion less than 0.002mm		



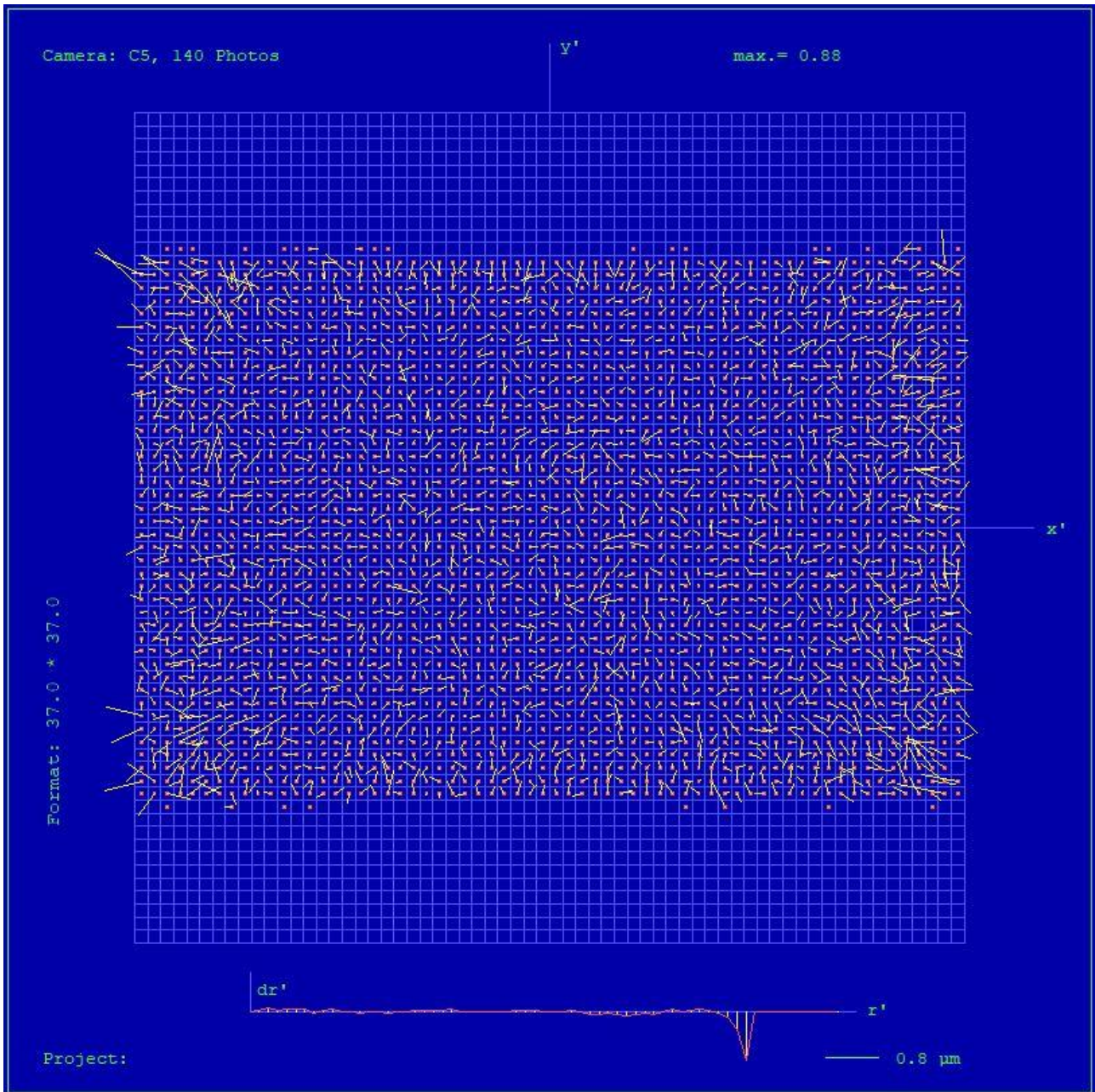
Full Panchromatic Image, Residual Error Diagram



Residual Error (RMS): **0.66 μm**



Green Cone (Cone 5), Residual Error Diagram



Residual Error (RMS): **0.45 μm**



Explanations

Calibration Method:

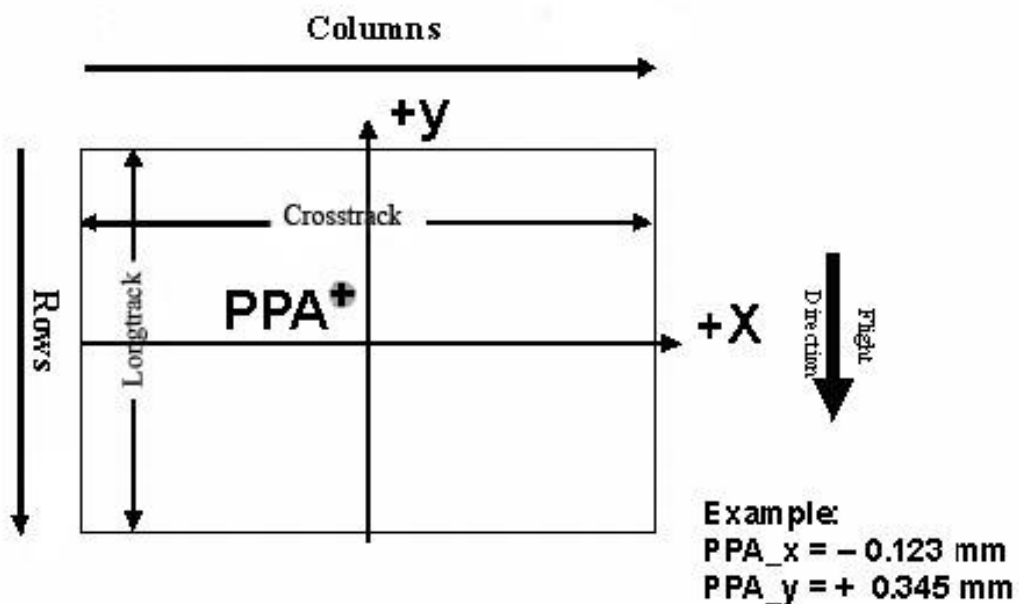
The geometric calibration is based on a set of 140 images of a defined geometry target with 394 GCPs.

Number of point measurements for the panchromatic camera : >16000
Number of point measurements for the multispectral camera : >60000

Determination of the image parameters by Least Squares Adjustment.
Software used for the adjustment: BINGO (GIP Eng. Aalen, Germany)

Level 2 Image Coordinate System:

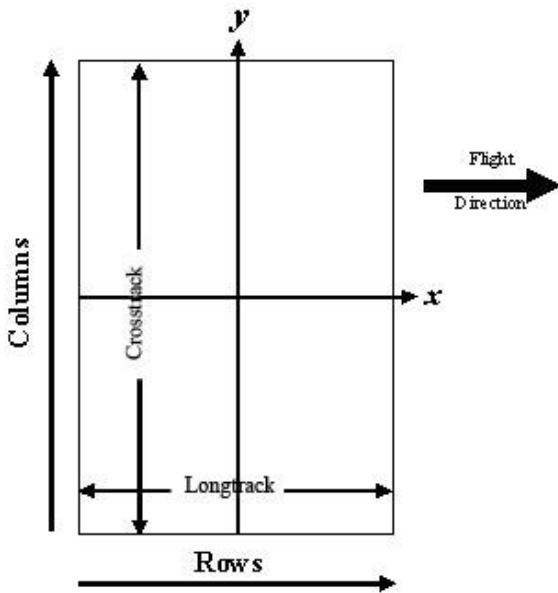
Lvl2, Camera prop. Orientation



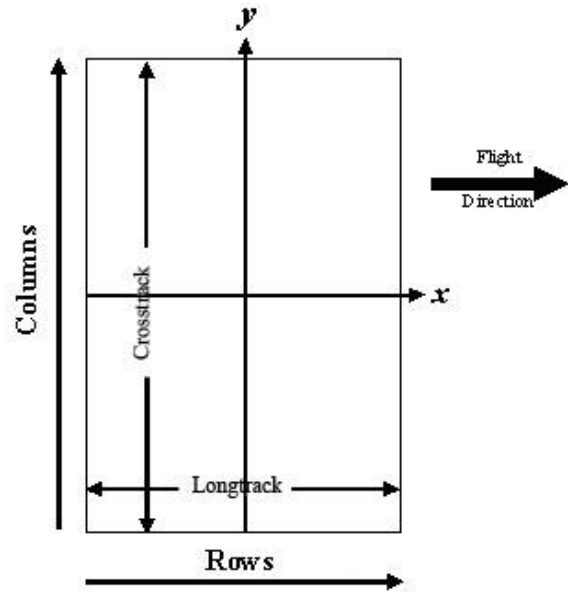
The image coordinate system of the Level 2 images is shown in the above figure. The basic image format and coordinate of the principal point in the level 2 image is given on page 4 of this report. The above figure shows the position of an example principal point at the coordinate (-0.123 / 0.345).



Level 3 Image Coordinate System:
(after rotation of 270° CW)



Panchromatic Image Format



Multispectral Image Format

Position of Principal Point in Level 3 Image

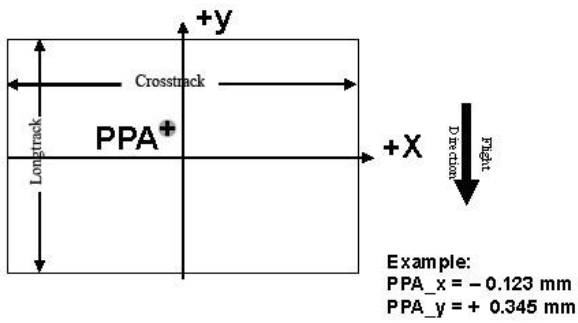
The position of the principal point in the level 3 image depends on the “rotation” setting used in UltraMap during the pan-sharpening step. The exact position relative to the image center is given in the table below as a function of the rotation setting used in UltraMap. The coordinates are specified for clockwise (CW) rotation in steps of 90 degrees, according to the principal point coordinate given on page 4 for high- and low resolution images.

Image Format	Clockwise Rotation (Degree)	PPA	
		X	Y
Level 2	-	0.000	0.000
Level 3	0	0.000	0.000
Level 3	90	0.000	0.000
Level 3	180	0.000	0.000
Level 3	270	0.000	0.000

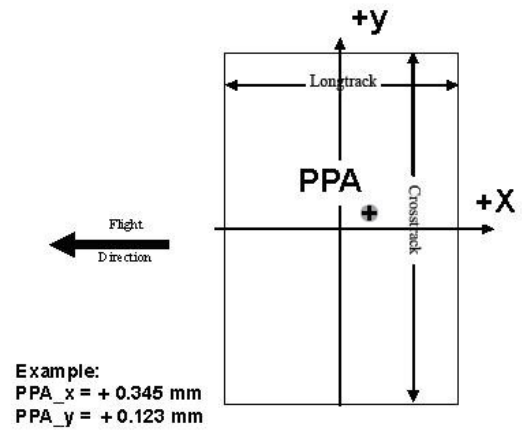


The coordinates in the figure below are only example values to illustrate the effect of image rotation on the principal point position, and do **not** correspond to the camera described in this report.

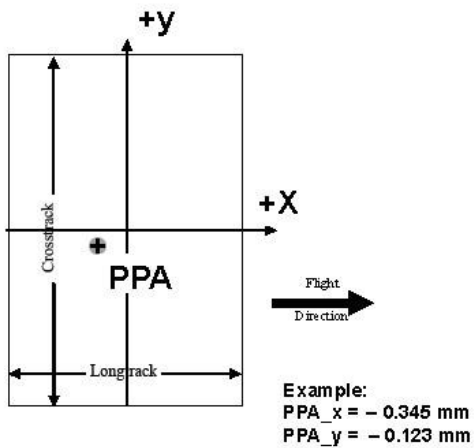
Lvl3, Rotation 0 deg clockwise



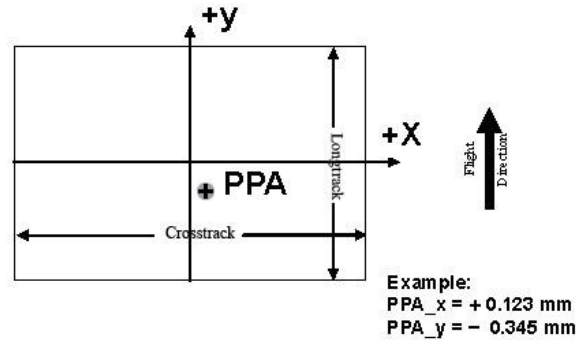
Lvl3, Rotation 90 deg clockwise



Lvl3, Rotation 270 deg clockwise



Lvl3, Rotation 180 deg clockwise





Lens Resolving Power

The following curves show the development of the modulation transfer function across different image heights of the panchromatic cones.

Please note that these values have been calculated and can vary up to 10% with optics from production (especially at high LP's).

The curves are given for the meridional (tangential) and sagittal (radial) component of signals at frequencies of 12.5, 25, 50 and 100 line pairs per millimeter.

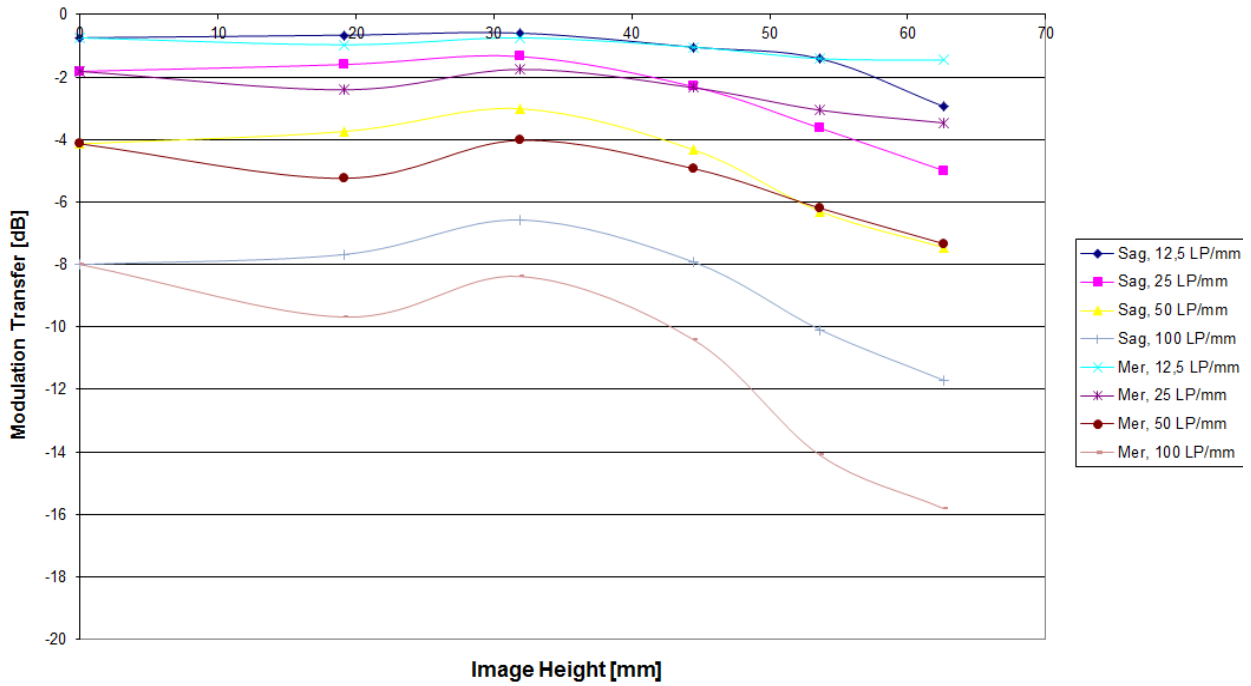
As the MTF is a function of the specific aperture size used, one set of curves is given for each aperture size.

Lens types

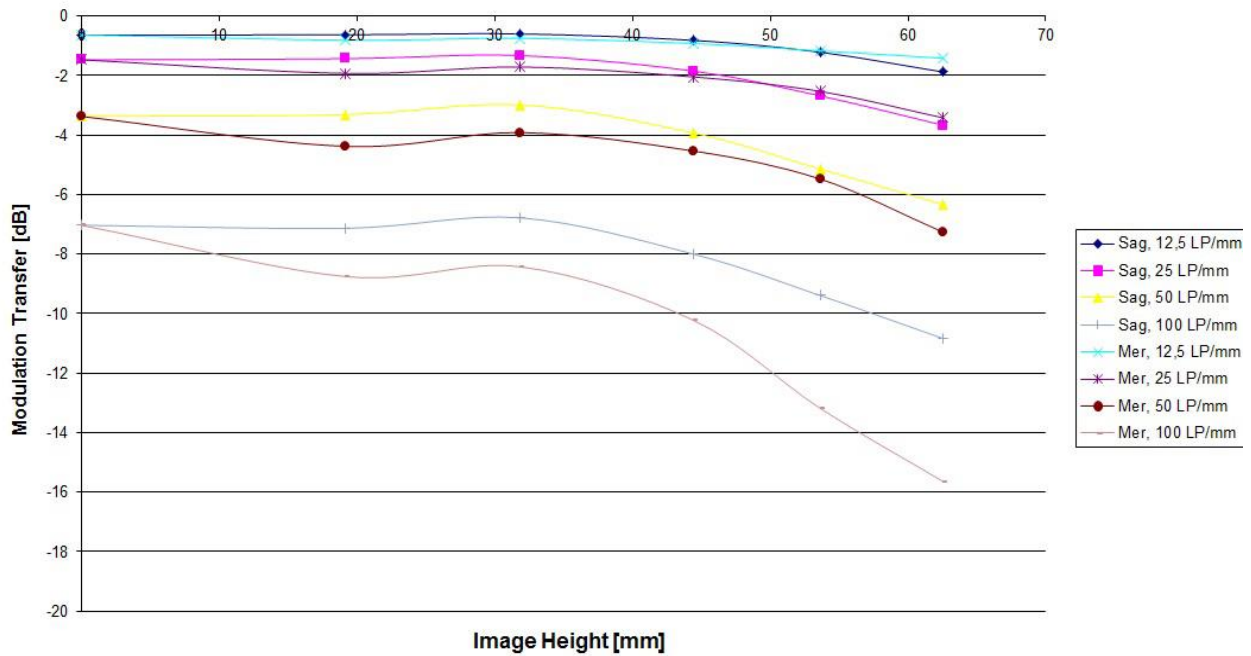
Cone	Lens
C0 (PAN)	Qioptic Vexcel HR Digaron 1:5,6/80mm, Qioptic GmbH, Germany
C1 (PAN)	Qioptic Vexcel HR Digaron 1:5,6/80mm, Qioptic GmbH, Germany
C2 (PAN)	Qioptic Vexcel HR Digaron 1:5,6/80mm, Qioptic GmbH, Germany
C3 (PAN)	Qioptic Vexcel HR Digaron 1:5,6/80mm, Qioptic GmbH, Germany
C4 (RED)	Qioptic Vexcel HR Digaron 1:4/27mm, Qioptic GmbH, Germany
C5 (GREEN)	Qioptic Vexcel HR Digaron 1:4/27mm, Qioptic GmbH, Germany
C6 (BLUE)	Qioptic Vexcel HR Digaron 1:4/27mm, Qioptic GmbH, Germany
C7 (NIR)	Qioptic Vexcel HR Digaron 1:4/27mm, Qioptic GmbH, Germany



Modulation versus Image Height - Aperture f/ 5.6

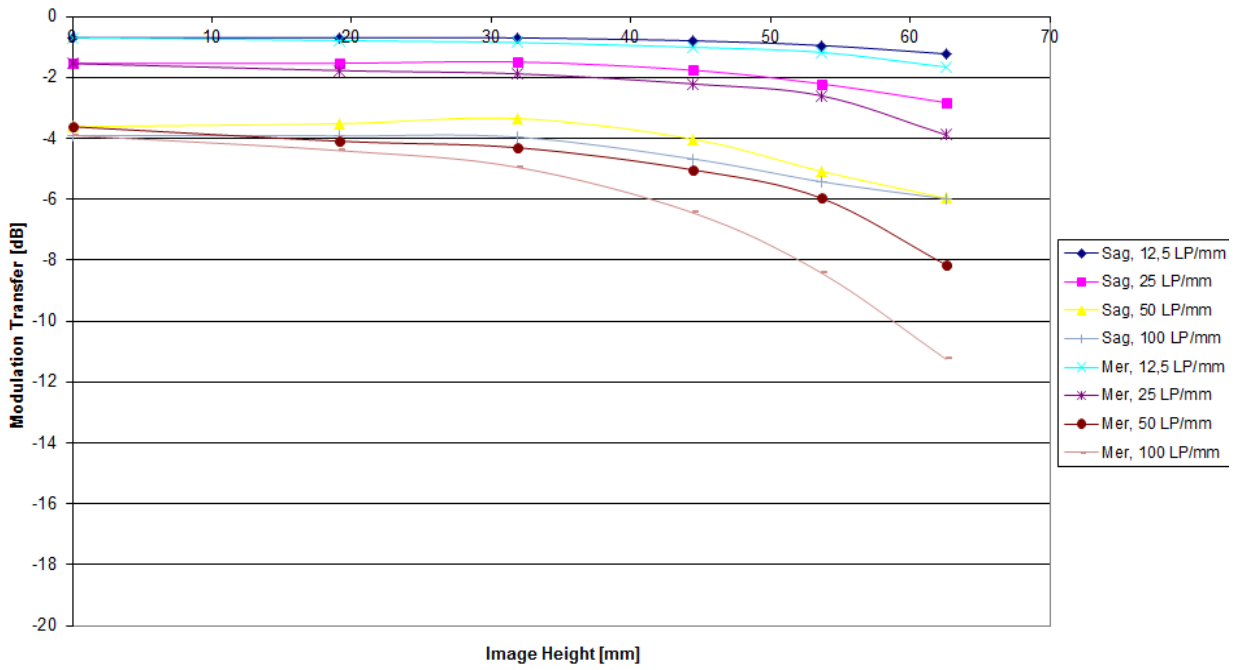


Modulation versus Image Height - Aperture f/ 6.7

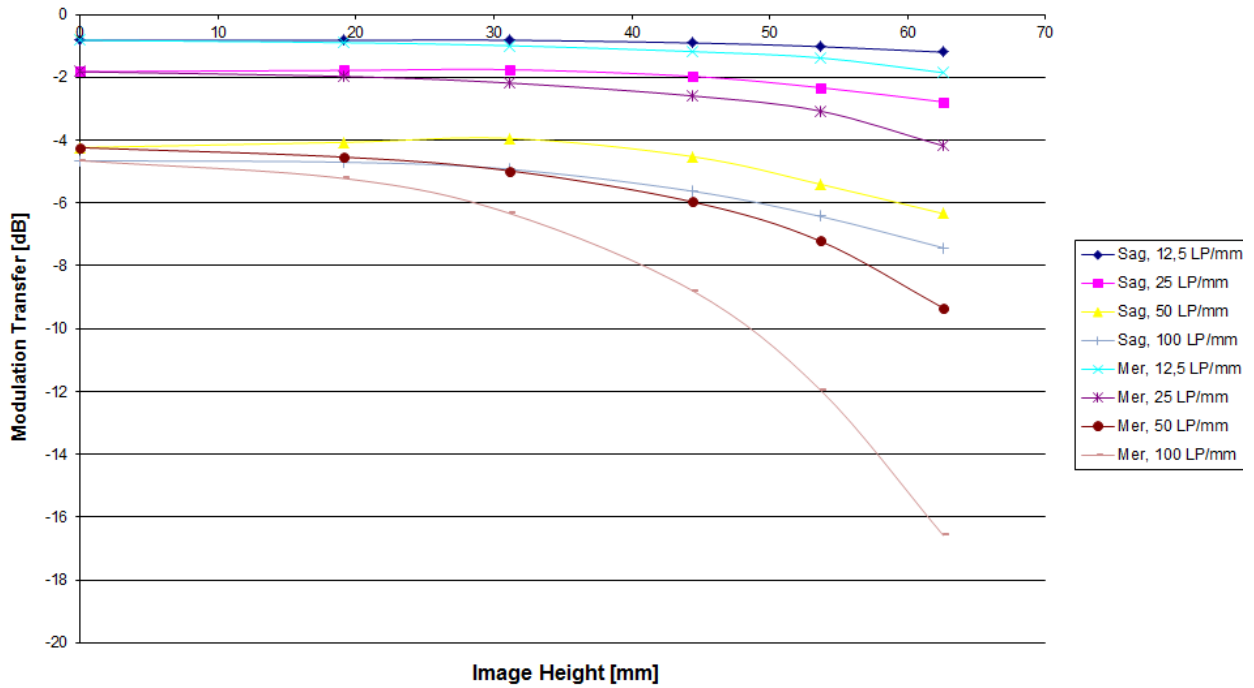




Modulation versus Image Height - Aperture f / 8

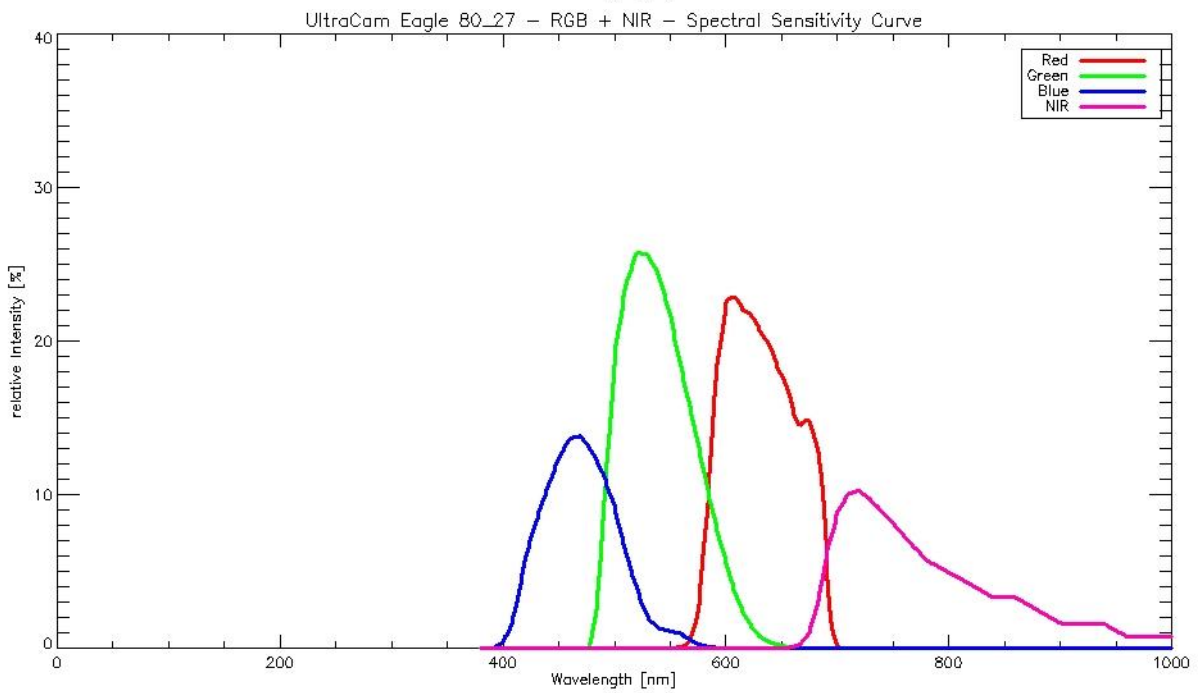
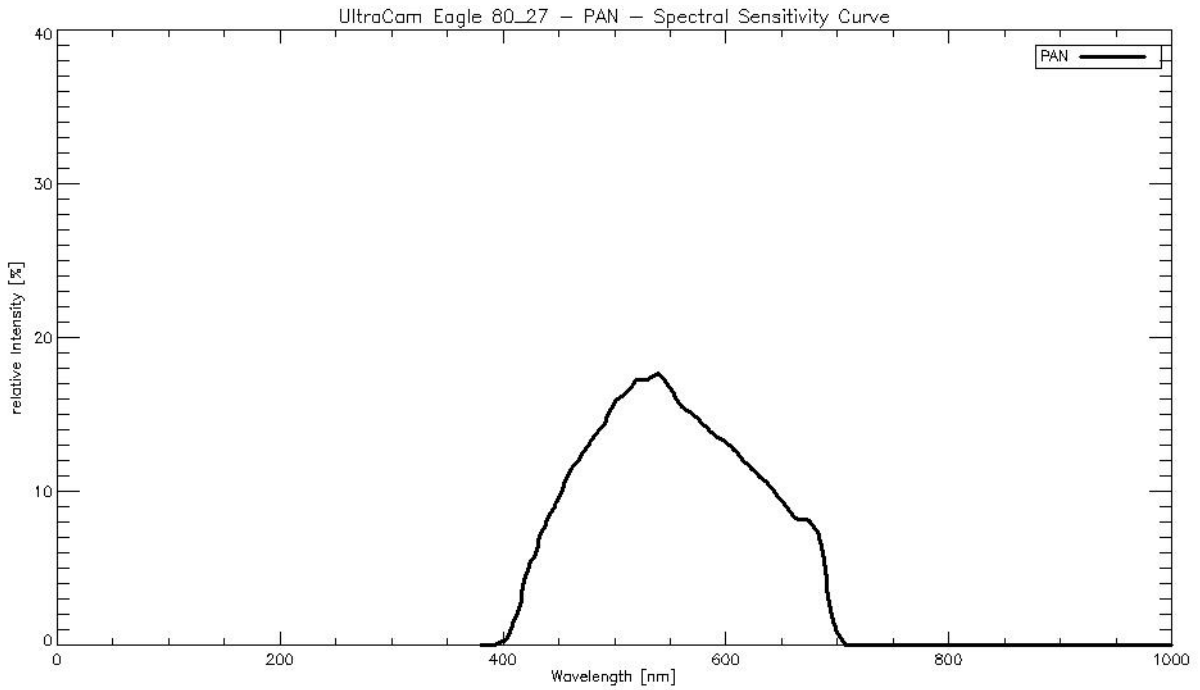


Modulation versus Image Height - Aperture f / 9.5





Spectral Sensitivity





ULTRACAM

Radiometric Calibration

Camera: UltraCam Eagle M3
Serial: 431S91288X112115-f80

	PAN	R, G, NIR	B
Used Apertures	F5.6	F4.8	F4.8
	F6.7	F5.4	F4.8
	F8	F6.7	F4.8
	F9.5	F8	F5.6
	F11	F9.5	F6.7
	F13	F11	F8
	F16	F13	F9.5
	F22	F19	F13

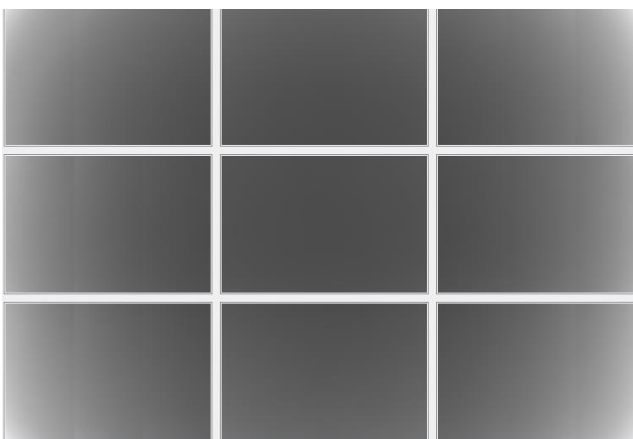
Dead Pixel Report: see Appendix I



Calibration of Vignetting for working Aperture F6.7

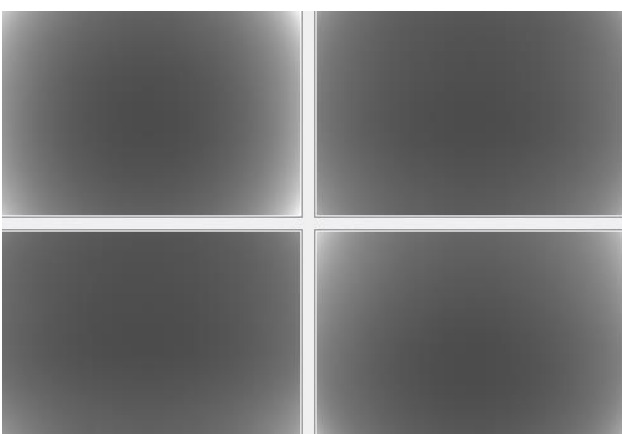
	PAN	R, G, NIR	B
Aperture	F6.7	F5.4	F4.8

Graphical Overview of Pan Sensors:



00_00	01_00	00_01
02_00	03_00	02_01
00_02	01_01	00_03

Graphical Overview of Multispectral Sensors:



04_00 (RED)	06_00 (BLUE)
05_00 (GREEN)	07_00 (NIR)



Explanations

Calibration Method:

The radiometric calibration is based on a series of 50 flat field images for each aperture size and sensor. The flat field is illuminated by eight normal light lamps with known spectral illumination curves.

These images are used to calculate the specific sensitivity of each pixel to compensate local as well as global variations in sensitivity. Sensitivity tables are calculated for each sensor and aperture setting, and applied during post processing from level 0 to level 1.

Outlier Pixels that do not have a linear behavior as described in the CCD specifications are marked as defective during the calibration procedure. These pixels are not used or only partially used during post processing and the information is restored by interpolation between the neighborhood pixels surrounding the defective pixels.

Certain pixels that are named Qmax pixels due to the fact that they can only store and transfer charge up to a certain maximum amount are detected in an additional calibration step. These pixels are treated differently during post processing, since their behavior can affect not only single pixel values but whole columns.



ULTRACAM

Shutter Calibration

Camera: UltraCam Eagle M3
Serial: 431S91288X112115-f80

Panchromatic Camera: 4 * Prontor Magnetic 0 HS
Prontor-Werk Alfred Gauthier GmbH, Germany

Multispectral Camera: 4 * Prontor Magnetic 0 HS
Prontor-Werk Alfred Gauthier GmbH, Germany



Calibration of Shutter Release Times:

The shutter release times measured during the calibration describe the time from the moment when the electrical current through the shutter is turned off by the electronics, until the shutter is mechanically closed.

This time is relevant for the exposure control and needs to be known before image recording can take place.

Currently used SRT values (operation values):

Cone Number	Lens Serial Number	SRT F5.6 [ms]	SRT F6.7 [ms]	SRT F8 [ms]	SRT F9.5 [ms]	SRT F11 [ms]	SRT F13 [ms]	SRT F16 [ms]	SRT F22 [ms]	Measurement Tolerance [ms]
C0 (Pan)	12 09 99 26	6.60	6.82	7.17	7.36	7.61	7.67	7.89	8.17	+/- 0.2
C1 (Pan)	12 09 99 31	7.12	7.34	7.64	7.90	8.03	8.16	8.36	8.66	+/- 0.2
C2 (Pan)	12 09 99 30	6.43	6.68	7.06	7.31	7.40	7.55	7.78	8.12	+/- 0.2
C3 (Pan)	12 09 99 25	6.41	6.62	6.94	7.19	7.33	7.42	7.53	7.92	+/- 0.2
C4 (Red)	12 09 99 36	7.61	7.67	7.82	7.88	8.03	8.17	8.32	8.51	+/- 0.2
C5 (Green)	12 09 99 38	7.36	7.47	7.65	7.72	7.79	7.97	8.09	8.29	+/- 0.2
C6 (Blue)	12 09 99 37	7.67	7.68	7.69	7.79	7.96	8.12	8.16	8.44	+/- 0.2
C7 (NIR)	12 09 99 34	8.10	8.10	8.23	8.40	8.69	8.83	8.83	9.28	+/- 0.2



ULTRACAM

Electronics and Sensor Calibration

Camera: UltraCam Eagle M3
Serial: 431S91288X112115-f80

Panchromatic Camera: 9 * FTF9060-M Area CCD Sensor by DALSA
Multispectral Camera: 4 * FTF9060-M Area CCD Sensor by DALSA



Calibration of Negative Substrate Voltage (VNS):

For optimum performance of the DALSA CCD sensors, the negative substrate voltage is adjusted to a value specified by DALSA.

This voltage value is measured to achieve the best anti-blooming performance possible for each particular sensor.

Currently used VNS and VOG values (operation values):

Cone_Sensor	Sensor Type	Sensor Serial Number	VNS Voltage [V]	VOG Voltage [V]
00_00	FTF9060-M	18 7966/003	22.40	6.33
00_01	FTF9060-M	18 7966/034	22.80	6.78
00_02	FTF9060-M	18 4458/052	22.00	6.68
00_03	FTF9060-M	18 4458/056	22.40	5.98
01_00	FTF9060-M	18 4458/041	22.20	6.25
01_01	FTF9060-M	18 4458/051	22.80	6.59
02_00	FTF9060-M	18 7966/069	22.40	6.32
02_01	FTF9060-M	18 4458/044	22.20	6.35
03_00	FTF9060-M	18 7966/050	22.40	6.35
04_00 (red)	FTF9060-M	18 4458/037	22.00	6.32
05_00 (green)	FTF9060-M	18 4458/060	22.40	6.14
06_00 (blue)	FTF9060-M	18 4458/047	22.00	6.11
07_00 (NIR)	FTF9060-M	18 7966/059	22.40	6.37



Calibration of Intensity Threshold for Exposure Control:

Each CCD sensor and electronics module varies slightly in global sensitivity and intensity scale.

Therefore the maximum possible intensity of each sensor needs to be measured to evaluate the sensitivity behavior of the CCD and electronics.

This value is used as a threshold for the exposure control dialogue shown in the in-flight user interface of the Eagle.

Currently used Threshold values (operation values):

Cone_Sensor	Sensor Type	Sensor Serial Number	Intensity Threshold [DN]	
			Tap 1	Tap2
00_00	FTF9060-M	18 7966/003	13520	12480
00_01	FTF9060-M	18 7966/034	13390	12640
00_02	FTF9060-M	18 4458/052	13650	12780
00_03	FTF9060-M	18 4458/056	13550	13140
01_00	FTF9060-M	18 4458/041	13540	12530
01_01	FTF9060-M	18 4458/051	12900	12080
02_00	FTF9060-M	18 7966/069	13810	12960
02_01	FTF9060-M	18 4458/044	13520	12710
03_00	FTF9060-M	18 7966/050	13900	13080
04_00 (red)	FTF9060-M	18 4458/037	13550	12740
05_00 (green)	FTF9060-M	18 4458/060	13490	12580
06_00 (blue)	FTF9060-M	18 4458/047	13510	12610
07_00 (NIR)	FTF9060-M	18 7966/059	13390	12490



ULTRACAM

Summary

Camera:	UltraCam Eagle M3
Serial:	431S91288X112115-f80
Laboratory Calibration Date:	Mar-16-2021
Camera Revision:	Rev04.00
Date of Report:	Mar-17-2021
Version of Report:	V01

The following calibrations have been performed for the above mentioned digital aerial mapping camera:

- Geometric Calibration
- Radiometric Calibration
- Shutter Calibration
- Sensor and Electronics Calibration

This equipment is operating fully within specification as defined by Vexcel Imaging GmbH.

Dr. Michael Gruber
Chief Scientist, Photogrammetry
Vexcel Imaging GmbH

Dipl. Ing. (FH) Helmut Jauk
Senior Project Engineer R&D
Vexcel Imaging GmbH



Appendix I

Dead Pixel Report:

Sensor number	Anomaly type	X-Coordinate	Y-Coordinate
---------------	--------------	--------------	--------------

C00-00

PIXEL: 147/4647
PIXEL: 1141/1165
PIXEL: 1724/1932
PIXEL: 3113/2308
PIXEL: 3974/4363
PIXEL: 4105/2365
PIXEL: 5060/2687
PIXEL: 5311/4810
PIXEL: 5839/2056
PIXEL: 5843/4953
PIXEL: 5843/4954
PIXEL: 6804/4618
PIXEL: 8899/2794
PIXEL: 224/ 487
PIXEL: 379/1432
PIXEL: 390/ 490
PIXEL: 468/ 937
PIXEL: 789/1298
PIXEL: 2985/4549
PIXEL: 3125/1693
PIXEL: 3489/3631

C00-01

PIXEL: 937/ 327
PIXEL: 943/1463
PIXEL: 2622/5599
PIXEL: 3498/4232
PIXEL: 3863/6012
PIXEL: 3986/3857
PIXEL: 5328/4598
PIXEL: 5823/4595
PIXEL: 6016/5470
PIXEL: 6181/2868
PIXEL: 6508/ 672
PIXEL: 6749/5639



PIXEL: 7597/4244
PIXEL: 7865/4563
PIXEL: 52/5886
PIXEL: 935/5358
PIXEL: 1003/5645
PIXEL: 3072/4198
PIXEL: 3072/4199
PIXEL: 4217/5254
PIXEL: 4217/5255
PIXEL: 6682/5158
PIXEL: 7639/4598
PIXEL: 7640/4598
PIXEL: 8167/ 574
PIXEL: 8935/4941
PIXEL: 9022/5890

C00-02

PIXEL: 121/1716
PIXEL: 2551/ 461
PIXEL: 3184/5843
PIXEL: 6812/1076
PIXEL: 95/5408
PIXEL: 212/1595
PIXEL: 509/1914
PIXEL: 791/2804
PIXEL: 2425/5610
PIXEL: 4530/5282
PIXEL: 5110/4223
PIXEL: 8016/4785
PIXEL: 8467/ 808
PIXEL: 8722/5786
PIXEL: 8805/5533
PIXEL: 9024/5925

C00-03

PIXEL: 726/2952
PIXEL: 1569/4051
PIXEL: 2352/4445
PIXEL: 2942/ 58
PIXEL: 3166/4924
PIXEL: 5269/4888
PIXEL: 5699/5436
PIXEL: 6505/2378
PIXEL: 7313/4253
PIXEL: 7695/5169
PIXEL: 7879/1776
PIXEL: 1413/1915
PIXEL: 2581/1746
PIXEL: 2655/2505
PIXEL: 3906/5979



PIXEL: 3906/5980
PIXEL: 9043/ 18

C01-00

PIXEL: 74/1632
PIXEL: 327/3558
PIXEL: 1371/2744
PIXEL: 3487/4466
PIXEL: 3515/ 628
PIXEL: 7026/5782
PIXEL: 7380/5766
PIXEL: 7945/4834
PIXEL: 188/3328
PIXEL: 4546/1653
PIXEL: 4886/3928
PIXEL: 7668/5373
PIXEL: 8360/5117

C01-01

PIXEL: 1137/2887
PIXEL: 1171/2639
PIXEL: 4571/3564
PIXEL: 4662/2538
PIXEL: 4665/2537
PIXEL: 4666/2537
PIXEL: 4786/5006
PIXEL: 6322/3744
PIXEL: 7088/3788
PIXEL: 8847/5471
PIXEL: 459/5075
PIXEL: 1064/5672
PIXEL: 2712/5215
PIXEL: 8870/5679
PIXEL: 9022/ 93

C02-00

PIXEL: 407/2395
PIXEL: 1668/4605
PIXEL: 1800/1829
PIXEL: 4517/1628
PIXEL: 5100/4265
PIXEL: 6357/5986
PIXEL: 7293/4285

C02-01

PIXEL: 65/5297
PIXEL: 3693/3797
PIXEL: 3824/5649
PIXEL: 4585/1101



PIXEL: 6070/5875
PIXEL: 6463/2313
PIXEL: 6806/2058
PIXEL: 7513/4551
PIXEL: 3855/1520
PIXEL: 8201/1072
PIXEL: 8593/4763
PIXEL: 8728/ 355
PIXEL: 8792/2441

C03-00

PIXEL: 562/5856
PIXEL: 1737/5122
PIXEL: 3180/1428
PIXEL: 3353/3769
PIXEL: 3361/5340
PIXEL: 3757/4283
PIXEL: 4621/4052
PIXEL: 5838/3513
PIXEL: 5935/2078
PIXEL: 5981/2682
PIXEL: 7293/ 408
PIXEL: 314/4831
PIXEL: 315/4831

C04-00

PIXEL: 203/ 40
PIXEL: 1042/5587
PIXEL: 2126/3583
PIXEL: 5730/4323
PIXEL: 5786/ 19
PIXEL: 7136/1354

C05-00

PIXEL: 28/1542
PIXEL: 609/ 342
PIXEL: 803/2285
PIXEL: 3195/ 629
PIXEL: 3884/ 792
PIXEL: 4696/4247
PIXEL: 5624/1014

C06-00

PIXEL: 8959/4168
PIXEL: 1630/5104
PIXEL: 4935/ 62
PIXEL: 7841/1185
PIXEL: 8480/2090
PIXEL: 1048/5160



PIXEL: 3157/5930
PIXEL: 3157/5931
PIXEL: 3158/5930
PIXEL: 7877/2486
PIXEL: 8958/4168

C07-00

PIXEL: 106/5976
PIXEL: 192/1365
PIXEL: 376/4315
PIXEL: 6970/3234
PIXEL: 8942/1752
PIXEL: 235/3729
PIXEL: 4956/5595
PIXEL: 4957/5595
PIXEL: 6115/1746
PIXEL: 6986/3635
PIXEL: 6987/3635
PIXEL: 8210/2004

Notes

COLUMN anomaly: all pixels below the Qmax detector at location (X,Y) may be affected.
PIXEL anomaly: single detector at location (X,Y) is not functioning within normal range

The Level0 coordinates exclude the two leftmost pixels containing the line index: the corresponding pixel can therefore be located at column (X+2,Y).



Appendix II

Calibration and Modification Dates

Type of Calibration	Laboratory Calibration Date	Modification Date	Modification Reason
Geometric Calibration	16.03.2021		
Radiometric Calibration	16.03.2021		
Shutter Calibration	16.03.2021		
Electronics and Sensor Calibration	16.03.2021		

Note: The above-mentioned Laboratory Calibration Dates represent the dates the camera was calibrated in one of our calibration labs for a full Laboratory Calibration. The Modification date represents a date on which the calibration has been modified due to a calibration enhancement or part exchange. It is an additional information and does not replace the Laboratory Calibration date in any way. With the Modification Reason, always the last modification to the calibration is highlighted